

MONTHLY REPORTING CHECKLIST

Submitted by: University of Michigan _____

Report Month: October 2002

TTP No.: ALO-7-C1-61 (UMichigan) _____

EARNED VALUE ANALYSIS DATA. Check **one** box in Line A and **one** box in Line B.

A. How is your project's schedule doing compared to your TTP baseline?

1. As planned.

B. How is your project's total cost doing compared to your TTP baseline?

2. As planned

PTS NARRATIVE INPUT CHECKLIST. Check that you have prepared the following narrative inputs:

1. **SIGNIFICANT ISSUES/PROBLEMS/CONCERNS:**
Note if there are any problems; otherwise, state "None." Report only problems considered "showstoppers" or fatal flaws (i.e., a lack of funding will cause the project to be shut down).

2. **CORRECTIVE ACTION:**
If a significant issue/problem/concern in Section 1 above is described, this section is required; otherwise state "None needed."

3. **SUMMARY ASSESSMENT:**
This should be a BRIEF paragraph summarizing the overall status of the project. This section is a synopsis of the entire report.

During this past month, work has continued in robust navigation, sensing, and radiation imaging. The novel OmniPede vehicle is progressing well, with a new innovation utilizing treads. Work using the Sick laser range scanner for map-building resulted in a better understanding of sources of artifacts from images. Work to upgrade an earlier generation gamma camera is proceeding rapidly with all 16 elements functional, and new efforts are exploring more efficient imaging techniques.

4. **COST VARIANCE:**
If you checked number 4 or 6 in the Earned Value Analysis section, you must provide an explanation here. Explain funding issues such as variances, carryover, commitments, incorrect FIS data. Avoid using only the words "Within budget." Some narrative is preferred.

Within budget.

5. **SCHEDULE VARIANCE:**
If you checked number 3 or 5 in the Earned Value Analysis section, you must provide an explanation here. Note if the project is on schedule, ahead of schedule, or behind schedule. If behind, explain what is being done to bring the project back on schedule.

On schedule.

6. **TECHNICAL STATUS:**
This is likely to be the longest section of the narrative and describes the technical accomplishments during the reporting period. Provide enough detail to inform, yet avoid extensive details that can confuse the reader.

TECHNICAL STATUS:

6.1 Obstacle avoidance

6.1.1 Elevation Map-building with the Sick laser rangefinder (LRF)

We conducted extensive further tests of the Sick rangefinder in an effort to pinpoint the source of erroneous data often found in the sensor's output. In earlier reports we referred to this erroneous data collectively as "artifacts." While until recently we believed that electromagnetic interference caused the problem, this assumption proved incorrect. Our latest understanding is that the artifacts are the result of an overflow condition in the data stream. Following is an explanation of what prompted this new insight. While still laboring under our incorrect assumption that electromagnetic interference was the culprit, we sent Sick (Germany) a detailed report on this problem. Sick responded that they had done tests with the scanner operating in strong magnetic fields and that the sensor was not affected by that. However, they told us that our model of the sensor had a "new" range mode, in which it could measure ranges up to 16 meters, and that our sensor happened to work in this mode by default. Unfortunately the documentation we have doesn't mention this mode, rather, it indicates that the sensor works either in 8-meter or 80-meter mode. It has overall been our experience that Sick's documentation is very poorly maintained and we had numerous problems because of missing or outdated documentation. However, we learned that Sick is now making great efforts to improve their documentation. This is relevant because Sick's laser rangefinders are the de-facto norm in mobile robotics.

Sick has now sent us updated documentation that explains how to switch from the default 16-meter mode to the 8-meter mode. We implemented the 8-meter mode and found that no more artifacts were produced in this mode. However, we still have not found a conclusive explanation why there were artifacts in the original 16-meter mode. We have a hypothesis on this issue but need to do further testing before we can reach a firm conclusion.

In the course of our investigation of the artifact problem we studied several papers on the internal physics of pulsed time-of-flight (TOF) rangefinders. It became apparent from our studies that some pulsed TOF rangefinders output an internally computed average of multiple "shots" in order to increase the measurement accuracy. We have contacted Sick with a request to clarify the operation of their unit in that respect. The issue is important because it may help understand the so-called "mixed pixels" problem we reported earlier.

6.2 Position Estimation

6.2.1 Odometry experiments: FLEXnav versus Kalman Filter

One important goal of ours is to compare our innovative Fuzzy Logic Expert navigation (FLEXnav) approach to sensor fusion with the more conventional Kalman Filter approach. As explained before, our Crossbow Inertial Measurement Unit (IMU) is ideally suited for this purpose because it offers two output modes: (1) a Raw Data mode and (2) a Kalman Filter mode. To compare FLEXnav with the Kalman Filter method we can use (1) the Raw Data mode in conjunction with FLEXnav to perform FLEXnav-based dead-reckoning, and (2) the Crossbow's Kalman Filter mode to produce the Kalman Filter-based comparison data. We believe that using the built-in Kalman Filter of a commercial product assures that we compare our FLEXnav system to a high quality reference.

In order to obtain some initial comparison data we performed several experiments with the Pioneer robot moving on rugged terrain. For this purpose we created an artificial rugged terrain course by using inclined wood panels as surfaces in addition to the rugged terrain properties of our existing sand box. We performed the initial experiment at a speed of 200 mm/sec. The average angular velocity in this experiment was about 30 degrees/sec. The robot was remote controlled to complete three laps (i.e., for a total of 1,080 degrees of turning) with a total travel distance of about 45 meters.

Our preliminary results obtained just at the end of this reporting period show the final positioning and angular errors to be notably smaller for our FLEXnav system than the ones computed using the Crossbow's Kalman Filter mode. In future experiments we will log results with greater care to provide a more in-depth assessment of the performance of the two methods. We should emphasize, however, that our current FLEXnav system is very rudimentary. We expect that it will take about 12 months to bring this technology to a more mature level.

6.2.2 Crossbow IMU – drift problem

In the course of the above-explained experiments we detected another flaw (in addition to many other flaws we found and reported on in the proceeding months) with the Crossbow unit. Specifically we noticed that the output of the Z-axis gyroscope was always affected by a predominant positive drift. We observed this error independently of the IMU's mode, i.e., Kalman Filter or Raw Data. In previous experiments we had ruled out that the source of these errors was RF or electrical noise, since the error remained even after we isolated the IMU electrically, using an additional power supply for the IMU, and magnetically, shielding the unit with Mu-Metal. The errors were such that in some cases, especially when the robot was turning clockwise, the error produced by the gyro due to the non-linearity of the scale factor was compensated by this drift since both have contrary signs.

After trying different approaches for detecting the source of this error we found that the most probable cause is the Crossbow's apparent sensitivity to acceleration or gravity. One would expect these errors to be small considering the low speeds of the robot. However, the error characteristic is non linear and thus produces errors of different magnitude when the robot accelerates or decelerates. Considering that the speed of the robot is in constant flux because of the rugged terrain and the remote control by a human joystick operator the robot was accelerating and decelerating continually and as the result the error due to this sensitivity to acceleration became significant.

We made one attempt so far to compensate for this error and it appears that we were able to reduce the heading errors significantly. However, we still have to verify the effectiveness of this compensation with experiments designed specifically to emphasize this error.

6.3 Novel mobility concepts

As reported for the first time last month, we have developed a break-through improvement to the OmniPede concept. This improvement, called OmniTread, is based on treads instead of legs to provide large moving surfaces all around the vehicle. Since all these treads are continuously in motion the vehicle will be propelled forward wherever it is in contact with the ground.

6.3.1 New OmniTread design

We are continuing the work on our new OmniTread design with great enthusiasm. This month we converged on key design decisions, especially regarding the drive train. The two competing designs that we considered were (1) use of a chain to that connects the tread-pulley axle through a transmission to the drive shaft spine, and (2) use of an exterior rolling pulley to pull the treads around. Design (1) requires two treads instead of one on each side of a segment because the chain has to pass between the treads to deliver power to the tread-pulley axle. Nonetheless, we deem this design preferable because it is not affected by mud or debris sticking to the treads, as is second design (2).

We created a Matlab script that relates tread velocity and torque based on the gearing to the efficiency of the drive components and thereby aids in the selection of gear ratios in the transmission. We are also testing a dynamics design software package, called "Working Model," to simulate stresses and torques in the transmission.

We have also already dimensioned parts of the chassis and transmission. We are currently deciding on the segment length, which depends on the minimum tread length the supplier can deliver. One of the design difficulties is the availability of closed loop treads of appropriate strength and dimensions. Commercially available timing belts are the focus of our search, although we will also look for tank treads used by model builders.

6.3.2 OmniPede design

In parallel with the development of the new OmniTread design we are still improving the mechanical design of the OmniPede through “non-invasive” measures. With that we mean that the modifications do not require a major redesign or the fabrication of complex parts for all seven existing OmniPede segments. Specifically:

1. We changed the ratio of the worm gears to double the velocity of the legs.
2. We increased the area of the footprint of each foot. This measure will help minimize foot-sinkage in loose ground, such as gravel or sand.
3. We identified an appropriate material that will cover the soles of the feet. The purpose of this material is to increase friction on slippery ground. This modification is the result of our observation that there is significant slippage when the OmniPede walks over smooth surfaces (such as linoleum) and thus loses a significant amount of speed.

6.3.3 Embedded control modules

We analyzed the number of wires required to control the valves, actuators, and feedback devices attached to each segment. The analysis showed that it would be unfeasible to originate these control wires for all segments from a single control module. Rather, we will equip each segment with its own embedded controller. All embedded controllers will communicate with the main onboard computer through a high-speed serial communication bus. Among suitable bus architectures we selected the so-called Controller Area Network (CAN). The CAN bus is used in the automotive industry because of its reliability and it operates at a fast speed of 1 Mbaud.

To implement this approach we did a literature search on appropriate micro-controllers. We found three micro-controller families that fulfill our Input/Output (I/O) requirements and provide a fast serial bus within a small package. These families are: (1) the PIC from Microchip, (2) the 68HC08 from Motorola, and (3) a 8051 compatible system from Atmel. The Atmel and Microchip components come in a 28-pin Dual in-line package (DIP) while the Motorola system comes in a larger 52-pin Plastic Leaded Chip Carrier (PLCC) package. All systems have flash memory. We are currently analyzing the costs of the respective development systems and the availability of software support.

6.3.4 Active pneumatic suspension vehicle

We continued work on the testbed for an active pneumatic-suspension mobile robot. We have almost completed the machining of all mechanical components and we also began assembling the testbed.

6.4 Infrastructure

6.4.1 Onboard computers

We found a workable way to use Toshiba Libretto mini-laptops on our space-limited Pioneer mobile robots. In the past we needed to use the Libretto docking stations in order to have USB ports available. The docking stations, in turn, require an uncommon supply voltage of 15 Volts, which is cumbersome to provide on the Pioneers. We have now found a PCMCIA-to-USB card that works reliably under Linux and thus eliminates the need for the docking stations.

6.4.2 MCIB Interface Code

We continued our efforts to convert existing DOS-based interface code for the MCIB motion controllers to real time Linux (LINUX RTAI). This task is not trivial since real-time Linux does not support floating-point functions. We completed this task and tested our converted code extensively to ensure that all the MCIB functions worked properly.

6.4.3 Control Code for the Gorilla

We have begun development of a software framework for control of the Gorilla mobile robot. In the past we had only very rudimentary control code in place with very limited functionality. The new framework will provide much greater functionality and it will allow the easy integration of new software modules, such as our position estimation system. The non-trivial aspect here is the timely communication of parameters and data between the Real-time Kernel and the User Space. The main portion of the Gorilla control code runs in the User Space, including the obstacle negotiation code and the laser rangefinder code. These functions, of course, also run in real-time, that is, while the robot is in motion. However, Linux makes a distinction between the Real-time Kernel, which provides multitasking with micro-second accuracy, and the User Space, which doesn't have tight timing constraints and runs at iteration times that depend on the complexity of the code and the CPU speed of the computer.

So far we developed control code functions for driving the robot forward and backward, resetting the driving potentiometer, calibration of the steering motor, and braking.

6.4.4 Gyro interface code

The currently used code for the interface between the onboard computer and the gyros suffered from large redundancies, which resulted in excessive processing times. We rewrote the code for both the KVH and the Crossbow gyros to make the data gathering more efficient. There was also a problem with synchronization: when the gyro was switched on before the software module was loaded, data didn't transfer correctly. We now corrected this problem for the KVH gyros and verified that our correction works well. We will implement the same correction for the Crossbow gyro.

6.5 Radiation Sensing and Imaging

We have integrated the images from an attached optical vision camera with the CSPD-2 gamma ray images. As reported earlier, we have spent considerable energy rebuilding this Gamma ray camera. As demonstrated during the site visit, the camera is now functional again and will serve as a comparison with newer designs.

We have submitted a patent application on the concept of a hybrid radiation camera as well as a new analytic technique to analyze and compare radiation imaging camera performances. A Journal article has been prepared on this topic and a presentation will be given at the upcoming IEEE Nuclear Science symposium and medical imaging Conference next month.

7. MAJOR ACCOMPLISHMENTS:

Note MAJOR accomplishments during the reporting period; "None" is a valid, *occasional* entry.

Lauro Ojeda presented our paper:

Ojeda, L. and Borenstein, J., "Mobile Robot Technology for Radioactive Waste Sites" at the Bioassay Analytical & Environmental Radiochemistry Conference, Las Vegas, Nevada, Oct. 28th - Nov. 1st, 2002.

MILESTONES. *Check that you have updated the status of your milestones.*

1. MILESTONE STATUS UPDATES:

Make sure you have provided a brief, one- or two-sentence comment on each active milestone and completion/new forecast date as appropriate.

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